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Thermal analysis and optimization of conical spiral receiver of solar parabolic dish concentrator.

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Abstract

The parabolic dish concentrator is efficient technology for utilization of solar energy to produce high temperature heat. The conical Receiver is able to hold a large amount of incoming energy from the concentrator compared to the other two shapes cylindrical and spherical. In this project, we are going to investigate Thermal Analysis and Optimization of Conical Spiral Receiver of solar parabolic dish concentrator by using Experimental setup. In this we insert Spiral Coil in Conical shape and going to investigate overall performance of the Concentrator. We focus on geometry and size of receiver, shape of the receiver, concentration ratio and heat losses related to receiver geometry. In this project, we mainly compare performance of conical spiral receiver with single plane spiral receiver. Through this analysis we are going to optimize variables to maximize the net thermal energy and to enhance overall performance of the parabolic dish concentrator.

Keywords: *Conical Spiral Receiver, thermal analysis, parabolic dish, concentration ratio.*

1. Introduction

Solar energy is a major source of non-conventional energy. Concentrating Solar Power (CSP) is technologies that use direct sunlight as a source to generate the heat. Generally, CSP has four technologies which are; Parabolic Troughs, Linear Fresnel, Parabolic Dish and Power Tower.Since the energy getting from the sun is totally free of cost so the utilization of solar energy is very beneficial hence there have been significant development in the field of solar energy technology is taken great interest in the recent years and continuous in these days also. For developing countries like India, providing energy to its citizens in an efficient and cost effective manner is a highly challenging task. Instead of excessive use of the fossil fuel and hydro power, use of excessive solar energy is the best option for fill the gap between supply and demand of energy. Sun causes the wind to blow, plant to grow, water to be lifted from oceans to return through rivers, waves on water bodies to be formed and temperature difference between top and bottom layers of oceans. All can work as the renewable energy source.

The parabolic dish concentrator is efficient technology to produce high temperature heat from solar energy. The conical Receiver is able to hold a higher amount of incoming energy from the concentrator compared to the other two shapes cylindrical and spherical.

1.1 Parabolic Dish Concentrators

Solar collectors are heat exchanger devices which absorbs the incident solar irradiation and convert a part of this to useful heat. This useful heat is transfer to a working fluid for various thermal applications. Parabolic concentrators are quiet popular because of its high concentration ratio and easy manufacturing. The two dimensional design of a parabolic concentrator is equals to a parabola. Parabolic dish able to focus all incident rays from the sun to a single point. It is not necessary to use the whole part of the parabola curve to construct the concentrator. Most of the parabolic concentrator employs only a truncated portion of the parabola. Nowadays two types of design of parabolic concentrator are available. One is a parabolic dish which focuses all reflected rays to single point, and the other type is a parabolic trough in which reflected rays are concentrate throughout the line. Both the types act as a reflector and are used in concentrating solar power system for solar power plants. Although this concentrator provide a high concentration, but it requires larger surface area to maximize the sun energy collection. For obtaining maximum efficiency, there is need of a good tracking system, which is expensive one.

1.2 Receiver

Solar receiver is a key component in parabolic dish concentrator system which is a typically a light-heat conversion system. Generally, in order to improve the thermal efficiency, coating layer of higher absorbtivity (nickel chrome black coating) for sunlight must be covered on the surface of the absorber tubes of cavity receiver. Higher thermal efficiency means more power will be generated in the same time, which will decrease the average cost and improve the competitiveness. Mainly there are two types of receiver for parabolic dish; the external type and the cavity type. The external receiver is usually cylindrical in shape. The solar flux is distributed on the outer surface of the receiver and absorbed by the fluid flowing through it. In cavity receiver the solar flux enters through one or more small apertures in an insulated enclosure. The cavity having proper tube alignment through which the receiver fluid flows. Both type of receivers have their advantages and disadvantages. The external type has a very wide acceptance angle and on other side cavity type has a small acceptance angle.Cavity type traps the solar flux more effectively and consequently has a higher efficiency than the external type.

2. Literature Review

Generally there are four technologies for concentrated solar power [CSP] which are Parabolic Troughs, Linear Fresnel, Parabolic Dish and Power Tower.The parabolic dish concentrator is most efficient for utilization of solar energy to produce high temperature heat. As mention before optimum receiver design is the key factor in the concentrating solar power system. The geometry of the cavity is such that it maximize the absorption of the entering radiation, minimizes heat losses by convection and radiation to the surrounding and at the same time accommodates the heat exchanger that transfers the radiant energy to the receiver fluid. The literature work of this paper contains overall review of the different types of receivers for concentrating solar power systems. Ahmed M. Daabo and Saad Mahmoud [1], shows the relation between the flux distribution on the internal surfaces of the cavities and their optical efficiency.However, the conical shape receiver received and absorbed, a higher amount of reflected energy than the other shapes. The optical efficiency found to be 70.1%, 75.3%, and 71.5% for the spherical, conical and cylindrical shapes respectively at surface absorptivity of 85%. The focal point position depends on the shape of the cavity receiver and its absorptivity. Therefore, there is an optimum distance for each type of design depending on these two factors. From this they conclude that The conical shape has the best illumination uniformity of all the investigated focal distance values. R. Pavlovic and A. Bellos [2], presents the optical and the thermal analysis of a parabolic dish concentrator with a spiral coil receiver. This analysis proved that the suitable position of the absorber is at 2.1 m from the reflector in order to maximize the optical efficiency for creating a relative uniform heat flux over the absorber. The energetic analysis shows that the collector performs well in great range of operating conditions. Its exergetic efficiency is getting greater with the higher inlet water temperature, a result which makes this collector ideal for higher temperature applications as solar cooling, electricity production, and polygeneration in buildings. X. Li, Y. J. Dai[3],shows The effects of inlet temperatures and volume flow rates on thermal performance are analyzed using the reliable numerical model and method. It can be found that the operational volume flow rates of 0.25 l/s and 0.35 l/s are suggested for the water and Therminol VP-1 under the geometry and operational conditions analyzed herein. K.S. Reddy, G. Veershetty[4] investigated solar parabolic dish power plant configuration depend on various parameters like the spacing between dish collectors, surface area required, percentage of the shadow. The normalized correlations were developed for east–west and north–south spacing distances as the function of latitude and operating hours. It is observed that the configuration corresponding to the plant operating from 1 h after sunrise to 1 h before sunset with spacing distance in east–west direction same as that of the shadow length after 2 h sunrise and in north–south direction equal to shadow length at noon for winter solstice gives the highest energy output with optimum land use. Huairui Li, Weidong Huang [5], In this paper they presents an analytical function to predict the performance of a parabolic dish concentrator with a cavity receiver. The optical efficiency of this is obtained by the integration of the optical efficiency of each reflecting point in the total reflecting area. The effect of directional characteristics of concentrated energy on the focal plane is also considered in this study. By using Gaussian and polynomial model of effective brightness distribution, efficiency of the system can be calculated quickly and precisely. The rim angle and size of the receiver of dish are optimized to maximize the net thermal energy. The results of this study shows that it gives better prediction to the performance of the dish with a windowed-cavity receiver. Ab Ghania, Chin Kim Ghana[6], studied on the impact of the Direct Solar Irradiance (DNI), collector and receiver to the value of solar irradiation intercept by a receiver and heat transfer to the receiver as well as the receiver loses in 25kW PD system. This study is using a simulation approach and Matlab Simulink was used as the simulation tool. The irradiation data obtained from the Meteonorm 7 Software and George Town, Penang in Malaysia has been selected as the location for simulation. The silver and aluminium was used as the reflective material and the intercepted factor is in the range of 0.9 to 1.0. From this they conclude that variations of the solar flux on the site, reflective material and the intercept factor influence the value of the rate of heat transfer to the receiver solar power intercept by a receiver as well as the receiver losses. Ossama Mokhiamar, Osama Elsamni [7], they design a lower cost parabolic dish concentrator for direct electricity generation. These types of models can be installed in rural areas which are not able to connect to external power supply. In this study they investigated three diameters of the dish; 5, 10 and 20 m and the focal point to dish diameter ratio is set at 0.3 in all studied cases. Their main focus on the selection of the appropriate dimensions of the reflecting surfaces. The dimensions of the rings and ribs which support the reflecting surface are optimized for the purpose of minimizing the entire weight of the dish to provide the minimum possible total deflection in the beams. The study applies full stress analysis of the dish using Autodesk Inventor. G. Veershetty, T. Srihari Vikram.[8] They investigated convective heat losses from the cavity receiver of parabolic dish which is carried out numerically by considering various parameters like the direction of wind, speed of wind, receiver configuration and receiver orientation. The wind effect on the receiver in different directions (u = _90_ to 90_), various range of operating speeds of wind (V = 0–10 m/s), different inclinations of receiver (b = 0–90_) and varying surface temperature on convective heat loss from the receiver are studied. To show the effect of wind on the heat loss from the receiver various parameters like velocity vectors, velocity contours, temperature contours are presented. The forced convection obtained to have likewise trends of free convection heat loss at various lower wind speed. However at higher wind speed, such a pattern is not observed. At lower wind speeds say less than critical wind speed (<2.5 m/s), forced convection loss is lower than natural convection for lower receiver inclinations and various wind directions ranging from _90_ and 0_. The forced convection loss is more significant than free convection heat loss above 5 m/s for all u and b values. For side-on winds, at different wind speeds above 5 m/s, irrespective of receiver inclination, the variation of forced convection heat loss is marginal (less than 5%).

3. Material and geometrical parameter selection

The main designing and manufacturing components for the experimental work includes the designing and manufacturing of the collector and the receiver. Other auxiliary components like pump, storage tank, pipe, valves, thermocouples etc. are directly procured from the market**.** Copper metal was selected for receiver material because of its high thermal conductivity (k=401W/mK). Aluminium sheet metal cover around the conical spiral coil to increase absorption rate and reduce wind losses.The frame of the dish will be made from galvanized steel and consisted of simple links welded together. The internal surface was covered with ionized mild steel of reflectivity of 92.5%. The mild steel sheet was cut into several pieces with same area of equal size. The parabola shape was formed by inter connecting the mild steel sheet with thin nuts on aluminium base.Temperature sensor – K- type thermocouple and temperature range150 to 450°C. Conical shape of coil is made by taking cone angle 60^0.

3.1 Selection of rim angle (Φ**):** It is defined as the angle which is describe between the axis and the reflected beam from the edge of the parabola. The rim angle measures the extend of truncation of the general parabola. A rim angle of 90° is preferred as it gives an optimum intercept factor & allows the depth to be focal point. $\emptyset r$= 90°. Due to this rim angle the shape of the dish such that its focal length is approximately same as the depth of the dish.

3.2 Mathematical background

Calculation of focal point from given width of aperture

$$W_a = 4f \tan\left[\frac{\emptyset r}{2}\right] \qquad [1]$$

By taking $\emptyset r = 90^0$ we get,

$$W_a = 4f \tan 45^0$$

$$Wa = 4f.$$

Calculation of absorbed radiation

$$S = I_b.\rho.\alpha.\gamma.k \qquad [2]$$

Useful energy gain is given by equation

$$Q = F_R.A_a.[s - \frac{Ar}{Aa}.U_L.(T_{fi}-T_a)] \qquad [3]$$

Thermal efficiency of collector

$$\eta_{th} = \frac{Qu}{Ib.Aa} \qquad [4]$$

Assuming following parameters;

Transmittance of cover , £ =0.94

Reflectance of collector, ρ =0.94

Absorbance of receiver, α =0.94

Thus by using above mathematical equations we obtained values of various parameters of the dish, receiver and operating conditions. Important values of the parameters are given in the below table 1.

Table 1. Different parameters of the solar parabolic dish concentrator.

Parameters	Values	Unit	Parameters	Values	Unit
Concentrator aperture diameter	2.20	[m]	Focal distance, f	0.57	[m]
Collector aperture Area, Aa	4	[m²]	Radius of parabolic dish reflector, R1	1.15	[m]
Surface area of parabolic dish	5.2	[m²]	Rim angle, Ψ	90^0	[-]
Solar beam radiation, Gb	800	[W m⁻²]	Concentrator depth	0.57	[m]
Receiver diameter, Dr	0.21	[m]	Geometrical concentration ratio, CRO	75	[-]

It is important to state that the coil geometry has an optimum design in order to capture high irradiation amount with a relative uniform distribution.

4. Experimental set up and Methodology

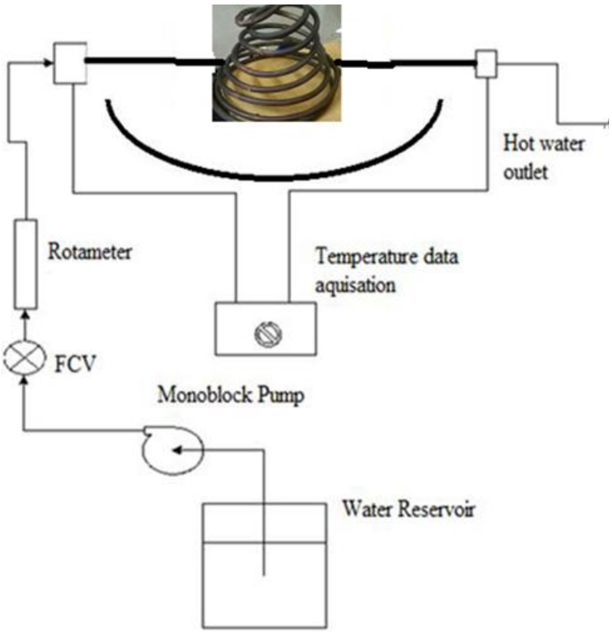

Fig 1. Experimental set up

The figure shows the complete assembly of the system. The input is taken from the reservoir with the help of a submersible pump. The water first flows from the reservoir to the input of the Receiver through pipe via rotameter A flow control valve is attached for flow rate controlling.

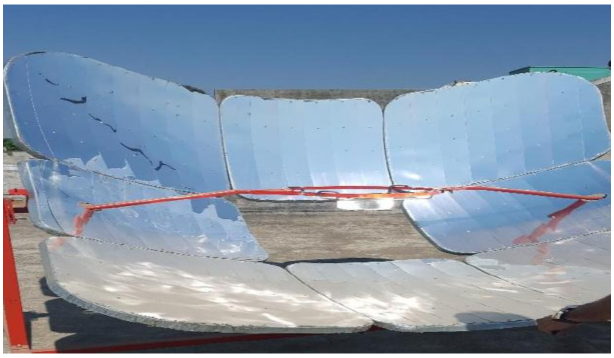

Fig 2.Parabolic dish concentrator

The water gains heat while flowing through the receiver coil and is collected in the collection tank at the outlet. Temperature sensors (K-type thermocouple) are provided at the inlet and outlet of the spiral coil for temperature measurement. An aluminum plate with a high reflectivity of 0.93 was rolled into a conical shape to cover conical coil to reduce losses. Thus after completing whole set up we have taken readings in various climate conditions in different months and at different time throughout the day. Maximum care was taken during the tracking to achieve the best results possible, because of errors due to the manual tracking dish. Again more errors due to the convective losses and manufacturing defects of dish and coil. Anemometer was used to measure the wind velocity so that proper account could be kept for the losses caused because of the wind.

5. Result and Discussions

The data collected over the time period has been properly organized and certain observations were made. This section focuses on the various parameters that effect the output temperatures obtained and ultimately the efficiency of the system. The effect of variations in geometry of the coil as well change in the receiver shape is analyzed.

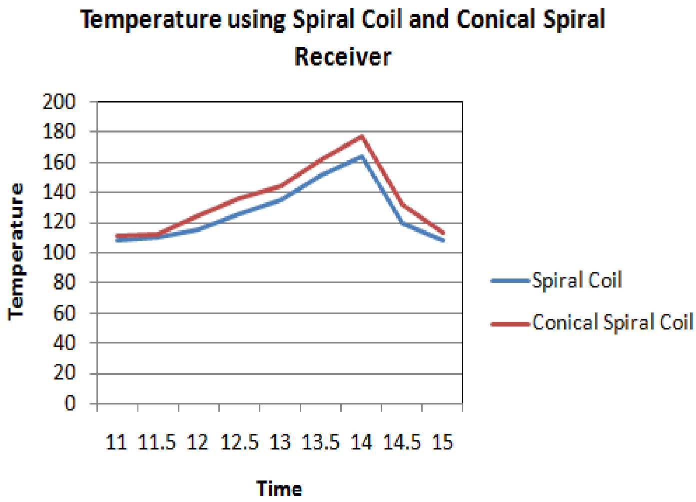

Fig 3.Temperature variation for spiral and conical spiral receiver.

Above fig shows the temperature variation with respect to time. It is seen that temperature range for conical spiral coil is more as compared to the spiral coil. This happens due to increase in solar absorption rate and reduction in heat losses compared to the spiral coil.

6. Conclusion

This work investigate Thermal Analysis and Optimization of Conical Spiral Receiver of solar parabolic dish concentrator. The following important point emerge from the study.

1. Conical spiral receiver able to absorb large radiation due to its geometrical shape. Therefore higher temperatures are achievable in conical spiral coil than spiral coil.

2. Conical spiral receiver has lower rate of heat losses therefore has higher efficiency.

3. Conical spiral receiver has achieved best flux distribution over other type of receivers.

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